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Toxicity of Cadmium in Soil-Plant-Human Continuum and Its Bioremediation Techniques

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Abstract

Cadmium (Cd) toxicity is highly detrimental for the human and largely originated from faulty industrial and agricultural practices. Cadmium toxicity can be observed in minute concentration and highly mobile in the soil-plant system and availability in soil is mainly governed by various physio-chemical properties of the soil. Cereals and vegetables cultivated in peri-urban areas, former mining and industrial areas accumulate Cd in toxic limit as they receive Cd from multiple ways. In general, when the total cadmium (Cd) concentration in soil exceeds 8 mg kg^{-1} , or the bioavailable Cd concentration becomes $>0.001 \text{ mg kg}^{-1}$, or the Cd concentration in plant tissue reaches $3\text{--}30 \text{ mg kg}^{-1}$ most plants exhibit visible Cd toxicity symptoms. The impacts of Cd toxicity are seed germination, growth, photosynthesis, stomata conductance, enzyme activities and alteration in mineral nutrition. The major source of Cd in human is food chain cycle and causes disorders like “*itai-itai*” disease, cancer, and nephrotoxicity. Cadmium harms kidney, liver, bone and reproductive body parts and may be fatal in serious condition. WHO recommended the tolerable monthly Cd intake are $25 \text{ } \mu\text{g kg}^{-1}$ body weights and in drinking water Cd concentration should not exceed $3 \text{ } \mu\text{g L}^{-1}$. It is hard to remove these potent and hazardous metals from the environment as they have long mean residence time but, can be converted into less toxic form through bioremediation. This chapter focuses on the effect of Cd toxicity in soil-plant-human continuum and its bioremediation techniques to mitigate the Cd- toxicity.

Keywords: bioremediation, cadmium, carcinogen, food safety, soil contamination

1. Introduction

Cadmium (Cd) is an element which is extremely toxic to humans and can cause adverse effects even in small doses. Cadmium is a non-essential trace metal, which plays no recognized role in human, plant and animal development and growth. Various Environmental Protection Agency classified Cd as one of the pollutant element and include it in the list of 126 priority pollutants [1]. Lithosphere, hydrosphere and atmosphere take part in the exchange of Cd in its bio-geo-chemical

cycle [2]. The aggregate industrial emission of Cd is vast and significantly contributed to bio-geo-chemical cycles, resulting Cd deposition in many ecosystems and hastening buildup of Cd both in nature and human food chain. Therefore, a variety of detrimental health effects of Cd have been identified in various parts of the world and these symptoms are increases progressively [3]. Cadmium (Cd), a hazardous heavy metal, falls into Group IIB of the periodic table and, its amounts ranging from 0.1 to 1 mg kg⁻¹ in environment [4]. According to recent data collected in 2011, 7500, 2500 and 2000 t of Cd was emitted by China, Republic of Korea and Japan whereas globally it was 21,500 t yr.⁻¹. After the industrial revolution, man-made activities have greatly intensified the CD level in environment. The produce and use of Cd containing batteries, dyes, electroplating, combustion of crude oil, paints (Cd use as stabilizer), phosphate fertilizer processing and waste water applications have added 3–10 folds higher Cd than natural methods to the ecology. The release of Cd into to the soil environment is responsible for some natural disasters, such as volcanic eruption, sea salt spray, wild fires, weathering of Cd containing minerals and rock, transportation and accumulation of Cd-polluted soil by water and wind [5]. Cadmium, resulting from occupational and non-occupational contact, has detrimental impact on human health through build-up of Cd in human body. Occupational contamination is primarily observed by the extraction and smelting of non-ferrous metals, the manufacturing and handling of composite-containing CDs, and e-waste recycling activities. Non-occupational Cd contamination is mainly done by smoking, feeding behavior and atmospheric Cd particles [5]. Cadmium is ingested into multiple organs within the human body

| Country | Adults N 19 | Children | Adolescent 14–18 years | References |
|------------------------------|--------------------------|-------------------------|---------------------------|------------|
| MAL/RDA ^a | 5.0E–02 ^b | — | — | [11] |
| RfD (oral reference dose) | 1.0E–03 | 1.0E–03 | — | [12] |
| Netherland | 2.01E–02 | 4.10E–02 | 1.60E–02 | [13] |
| USA | 1.08E–05 | 2.21E–05 | 8.63E–06 | [14] |
| Bangladesh | 5.17E–05 | 1.06E–04 | 4.13E–05 | [15] |
| Italy | 1.54E–05 to 5.48E–05 | 3.16E–05 to 1.12E–04 | 1.23E–05 4.38E–05 | [16] |
| Ethiopia | 1.16E–04 | 2.37E–04 | 9.24E–05 | [17] |
| Zimbabwe | 8.87E–04 | 1.81E–03 | 7.09E–04 | [18] |
| China | 2.05E–04 to 2.805E–03 | 4.18E–04 to 5.72E–03 | 1.63E–04 2.23E–03 | [19] |
| Sweden | 6.95E–05 | 1.42E–04 | 5.55E–05 | [14] |
| Uganda | 8.22E–05 | 1.68E–04 | 6.56E–05 | [11] |
| India | 8.03E–04 to 4.92E–03 | 1.64E–03 to 1.00E–02 | 6.41E–04 3.93E–03 | [13] |
| Pakistan | 3.67E–05 to 8.10E–04 | 7.49E–05 to 1.66E–03 | 2.93E–05to 6.47E–04 | [17] |
| France | 5.78E–03 | 1.18E–02 | 4.62E–03 | [12] |

^aMAL/RDA maximum allowable limit/recommended dietary allowance.
^bE–02 represents 1 × 10⁻².

Table 1.
Daily dietary intake of Cd (mg kg⁻¹ day⁻¹) through consumption of Cd contaminated vegetables.

i.e., kidney, liver, lungs, thymus testes, heart, epididymis, prostate, and salivary glands, leading to malfunctioning of multi-organ and ultimately death [6, 7]. The Itai-Itai epidemic with 184 patients and 388 possible victims was a well-known environmental hazard associated with Cd infection. Faulty farming practices and the use of hazardous plant agro-chemicals allow Cd to invade the food chain of humans. Commonly, trace elements level is typically higher in the roots, however in certain leafy vegetables (*e.g.*, lettuce and spinach), Cd is accumulated in plant leaves owing to its fast absorption and mobility within the plant system [8]. The estimation of quantities of Cd content in food materials indicates that vegetables and grains are the key factor of Cd in the food material, even though they are often present in animal products with a low quality. It is estimated that the everyday Cd ingestion by food material is 10.0–30.0 μg for adults in various countries [9, 10] (**Table 1**). Satarug et al. [20] reported that Cd level in vegetables varied from 0.001 to 0.124 mg kg^{-1} and intake of vegetables accounts >70–90% Cd susceptibility to humans. Remediation measures like washing the matrix, excavation and burial, and filed mechanization techniques have been followed in both limited and commercial scale but, not economically viable. An alternative strategy to mitigate the harmful effects Cd on soil–plant could be the use of bioremediation using suitable plants and microbes. So, in this chapter in brief the importance of Cd as a toxic element, its dynamics in the soil and plant and environment friendly measures to eliminate Cd pollution is discussed.

2. Cadmium contamination in soil and water

Cadmium (Cd) is a hazardous trace element disseminated extensively in the environment and causes implacable impact on human health even in very minute content [21]. Cadmium in lithosphere, sedimentary rocks and soil content 0.2, 0.3 and 0.53 mg kg^{-1} however in soil water and groundwater 5.0 and 1 $\mu\text{g L}^{-1}$, respectively [22, 23]. Cadmium contamination in soils and groundwater arises due to both natural and anthropogenic activities and cause harmful impact as its goes into human body through drinking water and foods [24]. Cadmium is mostly geogenic by origin whereas, majority comes from natural weathering and other sources are mining, casting and smelting, irrigation with sewage water, factories and vehicular discharges, and agrochemicals are major man-made causes of Cd pollution [25, 26]. Moreover, unmonitored and unsafe garbage dumping activities have intensely raised Cd levels in soil and water bodies. At end of 1980's it was reported that geogenic and anthropogenic sources mobilizes Cd to the biosphere 24,000 and 4.5 t yr^{-1} , respectively which depicted the supremacy of man-made activity [27].

Among the natural sources windblown soil particles are the main reason for atmospheric Cd contamination followed by wildfires, sea spray, volcanic emissions, and meteoric dust. In California, Burke et al. [28] estimated that forest fire enhanced the average Cd level in water bodies by 2 folds. Pacyna and Pacyna [29] and Richardson et al. [30] reported that the Global average annual emission of natural Cd is about 1400 t however, from anthropogenic sources it was 2983 t. In nature, Cd is present ubiquitously in all areas and interestingly it's presence can be seen in remote places like ice peak of the Himalaya and North and South poles [31]. In southern Germany mainly relies on agricultural activities has Cd concentration in soil deposition was upto 0.25 $\text{g (ha}^*\text{a)}^{-1}$ however, in industrial western Germany the Cd deposition was quite high upto 1.4 $\text{g (ha}^*\text{a)}^{-1}$ [32]. Thus, indicates that anthropogenic activities have greater potential in Cd pollution.

Cadmium content in the soil is positively correlated with the weathering of parent material but, unscientific practices have worsen the input, output balance

i.e., input through atmospheric precipitation, factory or agricultural operations, minus its output through leaching, erosion and uptake by the crops [33]. The average Cd concentration in unpolluted soils in worldwide is 3.6%, while amounts which might be differ across continents, countries and type of soils. Cadmium in soil >30% is critically consider as Cd pollution limit, however, it was found that Cd level in soil reduces proportionately as the distance between manufacturing units and urban areas increases [34, 35]. In soil, the predominant source of Cd contamination is through weathering of various rocks and minerals present in the soil [25]. Maximum quantity of Cd was found in sedimentary rocks (0.1 to 26%) as compared to metamorphic and igneous rocks which contains Cd in the range of 1.1–10% and 0.7–2.5%, respectively [36, 37]. Similarly, Liu et al. [36] reported that in mudstone and siltstone has higher Cd content (46%) whereas, carbonate rocks has only 17% Cd content. He et al. [38] documented that soils generated from metamorphic rock like shales are highly prone to Cd toxicity. The **Table 2** illustrated the various Cd containing rocks and minerals that may be recognize important for the incidence of Cd in the soil and water. Zinc (Zn) from sphalerite (ZnS) or smithsonite (ZnCO₃), and iron (Fe) from pyrite (FeS₂) and hydrous oxides of iron can be easily substituted by Cd [39]. Due to similarity in ionic radius Cd can able to replace several divalent cations (*i.e.*, Ca, Fe, Zn, Pb, and Co) from their rocks [37]. Gnandi and Tobschall [40] stated that Ca in apatite mineral can be substituted by Cd therefore

| Rock type | Average Cd content (%) | Mineral | Composition | Average Cd content (%) |
|--------------------------|------------------------|--------------|---|------------------------|
| Carbonate stone | 0.1 | Apatite | Ca ₅ (F,Cl)(PO ₄) ₃ | 1.4–1.5 |
| Ultramafic rocks | 0.2 | Sphalerite | (Zn,Cd)S | 2 |
| Schists | 0.2 | Smithonite | ZnCO ₃ | < 2.35 |
| Sandstone | 0.3 | Magnetite | Fe ₃ O ₄ | < 3.1 |
| Red shales | 0.3 | Silicates | — | 0.3–58 |
| Gneisses | 0.4 | Arsenopyrite | FeAsS | < 50 |
| Mafic rocks | 1.1 | Scorodite | FeAsO ₄ ·2H ₂ O | < 10–58 |
| Granitic rocks | 1.2 | Otavite | CdCO ₃ | 65.2 |
| Basalt | 2.2 | Greenockite | CdS | 77.8 |
| Obsidian | 2.5 | Pyromorphite | Pb ₅ Cl(PO ₄) ₃ | < 10–80 |
| Organic sediment | 5.0 | Calcite | CaCO ₃ | < 10–230 |
| Red clay | 5.6 | Marcasite | FeS ₂ | < 500 |
| Bituminous shale | 8.0 | Chalcopyrite | CuFeS ₂ | < 1100 |
| Limestone | 10 | Bindheimite | Pb ₂ Sb ₂ O ₆ (O,OH) | 1000–10,000 |
| Shale and claystone | 10 | Tetrahedrite | (Cu,Fe,Zn,Ag) ₁₂ SbAs ₄ S ₁₃ | 800–20,000 |
| Bentonite | 14 | Anglesite | PbSO ₄ | 1200 to >10,000 |
| Marlstone | 26 | Mn-oxides | MnO·nH ₂ O | < 10,000 |
| Oceanic manganese oxides | 80 | Limonite | FeO(OH)·nH ₂ O | < 10,000 |
| Phosphorites | 250 | Galena | PbS | < 30,000 |

Table 2.
Cadmium contents in different rocks and minerals.

| Source | Type of pollution | Country/Area | Maximum Cd level | Reference |
|---|--|----------------------------------|---|-----------|
| <i>Mining</i> | | | | |
| Pb mining and refinery | Atmospheric deposition | Příbram, Czech Republic | Soil: 48 mg kg ⁻¹ | [45] |
| Cu mining | Waste water | Canchaque, Peru | Soil: 499 mg kg ⁻¹ | [28] |
| Pb–Zn mining/refinery | Waste water | Coeur d’Alene basin, Idaho, USA | Groundwater: 77 µg L ⁻¹ | [46] |
| Fe–Ni–Co mining | Waste material | Several sites in Albania | Soil: 14 mg kg ⁻¹ | [47] |
| Au–Ag–Pb–Zn mining | Waste water | Chloride, Arizona USA | Groundwater: 19 µg L ⁻¹ | [48] |
| As refinery | Waste material | Reppel, Belgium | Soil: 79 mg kg ⁻¹ | [49] |
| Phosphorite mining | Mining waste, transport | Kpogamé, Hahotoé, Togo | Soil: 43 mg kg ⁻¹ | [50] |
| Zn smelter | Atmospheric deposition | Hezhang County, China | Soil: 74 mg kg ⁻¹ | [51] |
| Zn smelter | Waste material | Celje, Slovenia | Soil: 344 mg kg ⁻¹ | [52] |
| Pb–Zn mining/refinery | Atmospheric deposition and waste water | Jinding, China | Soil: 531 mg kg ⁻¹ | [53] |
| Mining activities | Waste water | BacKan province, North Vietnam | Soil: 4.26 mg kg ⁻¹ Irrigation water: 2.51 µg L ⁻¹ | [54] |
| Au–Cu mining | Waste water | Bolnisi, Georgia | Soil: 121.5 mg kg ⁻¹ | [55] |
| Coal mining | Mining waste and deposition | Anhui province, eastern China | Soil: 0.05–0.87 mg kg ⁻¹ | [56] |
| Cu, Mo and Ni mining | Mining waste and deposition | Yangjiazhangzh and Dexing, China | Soil: 22.8 mg kg ⁻¹ Sediment: 66.1 mg kg ⁻¹ | [57] |
| Coal mines | Atmospheric deposition and waste water | Singrauli, India | Groundwater: 108 ppb | [58] |
| <i>Industries</i> | | | | |
| Cement factory | Atmospheric deposition | Qadissiya, Jordan | Soil: 13 mg kg ⁻¹ | [59] |
| Various (e.g., textile, electroplating) | Waste water | Coimbatore, India | Soil: 12.8 mg kg ⁻¹ | [42] |
| Ceramic industry | Sewage sludge | Castellon, Spain | Soil: 72 mg kg ⁻¹ | [60] |
| Pigment manufacture | Atmospheric deposition | Staffordshire, UK | Soil: 16 mg kg ⁻¹ | [61] |
| Textile industry | Waste water | Haridwar, India | Soil: 83.6 mg kg ⁻¹ Groundwater: 40 µg L ⁻¹ | [62] |
| Metal industry | Atmospheric deposition | Unnao, India | Groundwater: 74 µg L ⁻¹ | [63] |
| Ceramic industry | Atmospheric deposition | Yixing, China | Soil: 5.9 mg kg ⁻¹ | [64] |
| Paper mill | Waste water | Morigaon, India | Soil: 31.01 mg kg ⁻¹ | [65] |

| Source | Type of pollution | Country/Area | Maximum Cd level | Reference |
|---|--|--------------------------------------|---|-----------|
| Power industry and industrial plants | Atmospheric deposition and waste water | Malopolska province, southern Poland | Soil: 16.9 mg kg ⁻¹ | [66] |
| Zinc-smelter plant | Irrigation through industrial effluents | Rajasthan, India | Soil: 96.8 mg kg ⁻¹ | [67] |
| Atlas Cycle factory | Irrigation through industrial effluents | Haryana, India | Soil: 9.81 mg kg ⁻¹ | [67] |
| <i>Waste management</i> | | | | |
| Disposal facilities | Leachate | Great lakes region, USA | Soil: 32 mg kg ⁻¹ | [40] |
| Household wastes | Waste water | Ikare, Nigeria | Groundwater: 580 µg L ⁻¹ | [6] |
| Landfill | Leachate | Taoyuan, Taiwan Alexandria, Egypt | Soil: 378 mg kg ⁻¹ Groundwater: 51 µg L ⁻¹ | [68] |
| Sewage and waste disposal | Waste water | Sekondi-Takoradi Metropolis, Ghana | Groundwater: 90 µg L ⁻¹ | [69] |
| Sewage disposal | Waste water and physical mixing | Sundarban, India | Soil: 1.70 mg kg ⁻¹ | [70] |
| Brownfield | Waste water | Xiangjiang River, China | Groundwater: 474 µg L ⁻¹ | [71] |
| Oil spill accident | Waste deposition and physical mixing | Sundarban, Bangladesh | Sediment: 0.82 mg kg ⁻¹ | [38] |
| Electronical waste recycling | Waste water | Krishna Vihar, India | Soil: 47.7 mg kg ⁻¹ Groundwater: 280 µg L ⁻¹ | [72] |
| <i>Agriculture</i> | | | | |
| Sewage sludge application | Irrigation | Several sites in Spain | Soil: 90 mg kg ⁻¹ | [73] |
| P fertilizer production | Atmospheric deposition | Rio Grande, Brazil | Soil: 9.3 mg kg ⁻¹ Groundwater: 3 µg L ⁻¹ | [32] |
| P fertilizer application | Infiltration | Cauvery River basin, India | Groundwater: 60 µg L ⁻¹ | [74] |
| Urban agriculture | Atmospheric pollution and soil contamination | Belo Horizonte, Brazil | Soil: 0.20 mg kg ⁻¹ | [75] |
| Sewage sludge application | Soil application | Jiangsu Province, China | Leachate: 0.14 mg kg ⁻¹ | [76] |
| <i>Urban areas</i> | | | | |
| Sewerage | Leakage | Rastatt, Germany | Groundwater: 5 µg L ⁻¹ | [1] |
| Road traffic | Infiltration | Celle, Germany | Groundwater: 2.34 µg L ⁻¹ | [9] |
| Over populated, E-wastes and industrialized | Infiltration and physical mixing | Western Uttar Pradesh, India | Groundwater: 0.07 mg L ⁻¹ | [77] |

Table 3.
Various types of cadmium contamination in soil and waterbodies.

Cd may be a natural adulteration in phosphate (P) minerals and phosphorite rocks that are essential for the manufacture of phosphate fertilizers. Unlike Eastern Europe, there is considerably higher Cd in agricultural fields of Western European and one of the reasons for this is use of P fertilizer from distinct source [41]. The Cd bioavailability is governed by several factors such as: pH, moisture content, soil texture, clay content and type, cation exchange capacity, quantity and type of organic matter (OM), hydrous oxides, etc. [38]. Cadmium is easily mobilize in the soil due to its weaker bonding between soil exchange sites (*i.e.*, OM, carbonate, and hydrous oxide) [42] and that is the key factor to increase bio-availability of Cd to plants, ground water as well as plant products.

Geogenic sources input only 10 percent Cd in the environment however, man-made emission input 90 percent Cd in the environment. Among the various man-made sources major contribution is from manufacturing and application of P fertilizers, petroleum oil burning, smelting and casting industries, effluents from cement factories, vehicular emission, sewage sludge, landfills, municipality solid wastes, and mining activities [43, 44]. The **Table 3** explained various anthropogenic activities and their impact on Cd build-up in soil and groundwater. Cadmium is mainly used in stabilization of plastics, pigments manufacturing, solar panels, nickel-cadmium batteries, and rust resistant steel production, agri-chemicals, solders, engine oil, and rubber and fabric industries [78, 79]. Brown et al. [80] reported that in 2015, globally Cd manufacture was ~24,900 metric tons and it was increases in the coming years. Among the anthropogenic sources mining and metal industries are the main reason for environmental Cd pollution followed by textiles industries, nonmetallic mineral products, fertilizers and agro-chemicals production, and leathers industries [81]. Landfills and municipal solid waste deposition are the major causes of soil pollution with Cd and in European countries municipal solid waste contain Cd level up to 3 to 12% [62]. Leachates from various sources are the main cause of Cd pollution in groundwater and Belon et al. [35] estimated that leachate form FYM, atmospheric deposition, inorganic fertilizers and municipal solid waste ranges from 10 to 25, 15–50, 30–55 and 2–5%, respectively. Another important source of Cd pollution in soil through the use of P fertilizers and P fertilizer used in various countries like Eastern Mediterranean countries, European countries and Germany the Cd content is as high as 770, 360 and 600%, respectively [37, 82]. Cadmium discharge and emitted from multiple sources gradually enters into the soil and then eventually bio-accumulates in food grains which ultimately leads to human health hazard.

3. Mechanism of Cd accumulation in plants and consequences

Cadmium (Cd) is a potent pestilential metal which enters primarily via plant roots, get distributed and accumulated in plant parts in different proportions and concentrations, hampering crop yield and deteriorating the quality of produce. It ultimately makes it way to enter food chain thereby possessing serious threat to human and animal health. Cadmium ranks 7 among the top 20 toxins and it enter to arable land through various industrial processes and farming practices [83].

3.1 Accumulation of Cd in plants

Accumulation of Cd in plant is facilitated by its mobilization, uptake and transport/distribution in various plant parts. Unscientific agricultural practices and industrial effluents are the major contributor of Cd in soil [84]. Phosphaic fertilizer

and sewage-sludge contribute to Cd pollution in agricultural soil. Concentration of Cd in plants is also an indicative of its concentration in soil; however various other factors including soil pH, organic matter content, interaction with other ions and plant species govern its availability in plants [85–87]. Meta data analysis of 162 wheat and 215 barley grain samples by Adams and associates, [88] showed grain Cd concentration is positively correlated with soil total cd content and soil reaction (pH). They also highlighted the fact that higher microbial activity, nitrification and application of sewage sludge increased the chance of Cd toxicity but, reclaiming the soil with liming may abate the chance of toxicity. Sauvé et al. [89] found that organic matter had almost 30 times more sorption affinity for Cd when compared with mineral soil in Canada which indicates the importance of quality of organic matter in binding and accumulating Cd. It is assumed that lowering of pH will facilitate Cd availability to plants, but it might not hold true for soils with lower pH and high organic matter.

Before apprehending the mechanism of Cd accumulation in plants, one has to understand uptake and translocation of Cd inside plants. Ability of plants to take up Cd depends upon numerous factors like total Cd content in soil solution, soil reaction (pH), redox potential (Eh) and moisture content, soil organic carbon content, soil temperature, and last but not the least interaction among different elements. Primarily Cd enters plant through roots. Once in roots, Cd can get stored or exported to shoots through xylem. Cadmium is both xylem and phloem mobile [54, 74]. There are two possible mechanisms of Cd translocation into the plants and subsequently to the grains. These are: (i) Xylem mediated translocation to the sink i.e. grains (ii) Active transportation to various plant parts culm, rachis, flag leaves, external parts of the panicles and followed by phloem mediated mobilization to grains [90] and Schematic representation of Cd uptake and subsequent translocation in rice was shown in **Figure 1**. Root cell membrane located transporters take key role in Cd uptake in plants [91].

Cadmium uptake and accumulation in plants must undoubtedly be under control of multiple genes which contribute quantitatively in stage-specific, tissue-specific, environment-specific to Cd transport, accumulation and sequestration in plants [92]. In a study conducted by Hédiji et al. [72] on long term exposure of

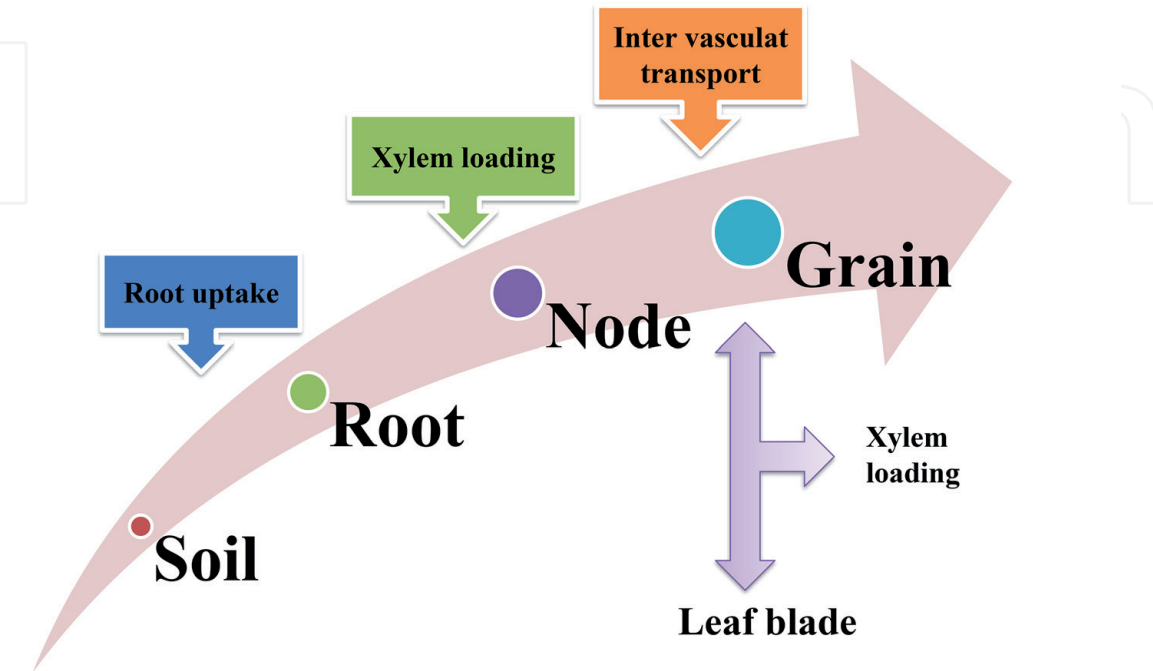


Figure 1.
Schematic model of Cd uptake process from soil to grains in rice.

Cd on tomato (*Solanumlycopersicum* L.) concluded that, impact of Cd toxicity is highly dose specific and significantly correlated with soil nutrient status. Whereas, in higher dose severely affecting the plant growth and metabolism by altering the nutrient partitioning. Several genes are responsible to carry out these processes.

3.2 Consequences to plant health

The impact of Cd toxicity in plants is still a closed book thing but, recent advances in plant physiological studies helped the researchers to answer the questions. Clemens [54] reported that the major influence on Cd toxicity in plants is nutrient imbalance by regulating the normal work of transporters peculiarly in fruit plants. For instance, the concentration of K, Zn, and Fe in developing fruits falls off drastically at the expense of Ca and Mg. The antagonistic relationship between Cd and K is well documented like sub-optimal K concentration in the pericarp which disrupts the normal bio-chemical cycles like bio-synthesis of protein, enzymatic activity and membrane bound activities such as sustaining cellular turgidity [54].

4. Consequences to human health

According to International Agency for Research on Cancer, Cd is highly inimical and labeled as class-I carcinogenic compound to mammalian health. Cadmium may not be toxic to the plants that accumulate it, yet are toxic to animals and humans feeding upon it. Cadmium makes its entry to human body either from food, water or breath and a little amount enters through skin. Majority of Cd entering to human body is either breathed out or excreted in feces, whereas only one-quarter of it gets into human body through breath and one-twentieth from food. People working in industries that release Cd are more prone to get affected by Cd toxicity because they might breathe, eat or drink Cd in air, food or water. Cadmium with biological half-life of 10–30 years, generally gets accumulated in kidneys and liver and slowly leaves human body through urine or feces [93, 94]. Researches around the world indicate that daily cadmium intake from all sources is very low in case of general population which range between 10 and 25 μgday^{-1} , however the tolerable daily intake established by WHO is 60 and 70 10–25 $\mu\text{g day}^{-1}$ respectively, for adult women and men.

5. Cadmium toxicity in humans

Human health due to Cd is an emerging issue and needs urgent attentions [52]. During the process, 10–50% of the cadmium dust is consumed according to the particle size. Digestion is higher for people that have an iron, calcium or zinc deficiency. The main source of human cadmium toxicity is considered to be tobacco smoking other than industrial exposures and food habit [95–98]. Cd toxicity is developing gradually in the human body and eventually causes different negative health effects, particularly bone loss and nephron toxicity.

5.1 Absorption and distribution

Cd is passed across the body after assimilation, usually linked with a bunch of sulfhydryl containing protein such as metallothionein. Typically 30% stores in liver and kidney; the remaining spread across the body, with an independence half-life about a quarter of a century [99]. Blood, hair and urine Cd levels are indicator of

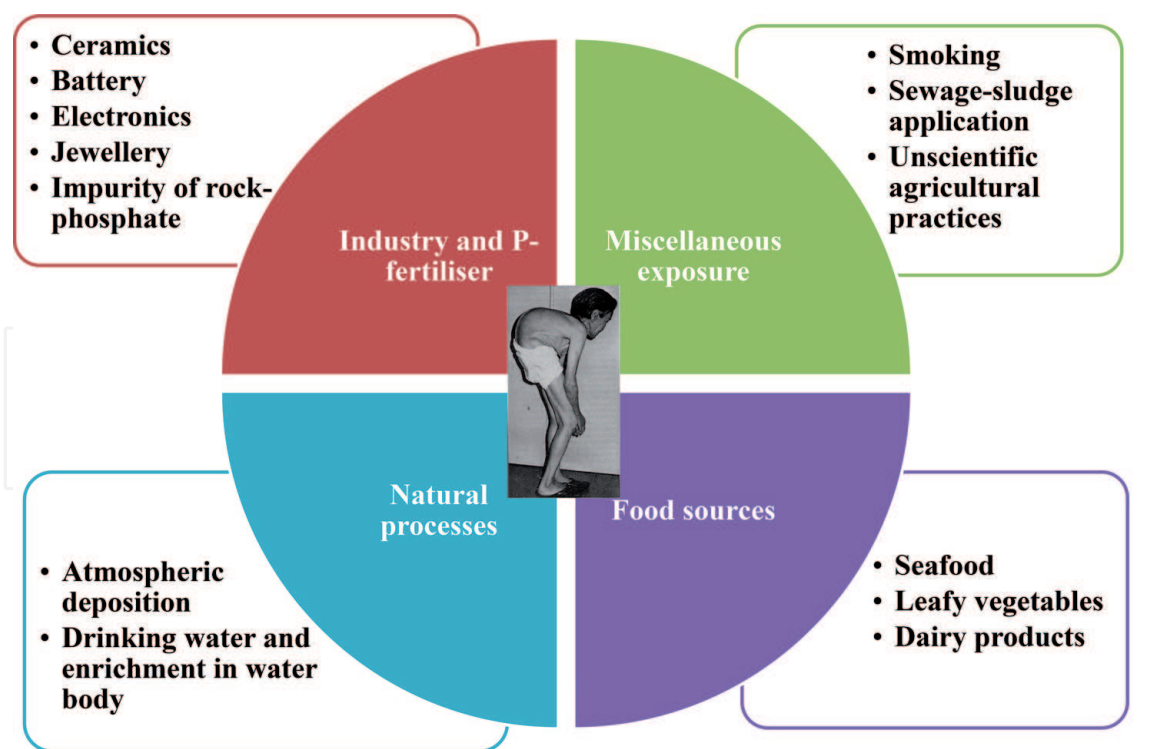


Figure 2.
Mechanisms of cadmium toxicity in humans.

potential toxicity but, to get the actual toxicity level urine stimulation test with the subjects body weight is highly important [100].

5.2 Mechanisms of toxicity

As previously mentioned, Cd induced epigenetic changes in DNA articulation by oxidative pressure, impediments or guidance for transport pathways particularly in the kidney [98] (**Figure 2**). Extreme impedance to the physiological function of Zn or Mg is introduced by other pathological mechanisms [99]. Restriction of the heme and the weakening of mitochondrial work which is likely to cause apoptosis [47]. Glutathione explosion has been found alongside the auxiliary protein contortion attributable to the official Cd in sulfhydryl bunches [100]. Cooperation with other hazardous metals, such as lead (Pb) and arsenic (As) hastens these impacts [101, 102].

6. Clinical toxicity

The major site of Cd toxicity is kidney where a fragment S1 of the proximal tubule is a majorly targeted and disruption in mitochondrial protein synthesis due reabsorption of glucose, bicarbonate and phosphate clinically known as Fanconi disorder [76, 103]. Cadmium can also inhibit the digestion of vitamin D in the kidneys with progressively rises of issues like osteomalacia, osteoporosis, renal-around broking and calcium malabsorption [103–105]. Cadmium has multiple deleterious effects on the cardiovascular framework like adverse impact on vascular endothelium consistency [95, 106]. Cd links to sudden coronary death marginal blood vessel dysfunction, increased intima media thickness and scattered myocardial necrosis [64, 107]. In comparison, low-recurrence listening was substantially decreased by people with elevated urinary Cd levels [108]. In comparison, high-urinary Cd rates

have decreased cognitive power. Cadmium is assumed to be the carcinogenic agent Class B1 by the United States Environmental Protection Agency [46]. Conflicting research links Cd adoption and denies bosom malignant development [88, 94, 109]. Cd was associated to pancreas and lymphoma cell disturbance [88]. Vegetables developed in Cd-defiled soils can possibly cause toxicological issues in people particularly in developing women [110]. A few different components like low admission of Ca, vitamin D, and minor components, for example, Cu and Zn can build this sum. Thus, daily entry of Cd by Cd is exceptional due to the fusion of Cd in diets and the human dietary propensities. The mean daily use of Cd (DICd) uses the following formula as a general basis:

$$DI_{Cd} = (C_{Cd} \times C_{factor} \times D_{food\ intake}) / BW_{average\ weight}$$

DI_{Cd} symbolizes daily intake of Cd, C_{Cd} Cofactor, intake of D_{food} and $W_{average}$ weight are Cd fixations in vegetables, transition factor (new weight to dry weight), and human consumption of vegetables every day and regular body weight respectively. **Table 2** describes the DI_{Cd} figures given in different countries by the use of Cd-sullied vegetables. The number of inhabitants in the Netherlands unmistakably ingests the most notable Cd from the available information through defiled vegetables, followed by France and USA. The introduced data shows that the use of Cd contaminated nourishments is a significant implementation course. In these lines, in order to avoid harmful health consequences, the intake of infected vegetables should be reduced to the fullest degree possible. Different remediation steps can also be introduced in infected soil to carry the Cd concentration to a reasonable amount. In contrast, DI_{Cd} 's principles are based on a few experiments worldwide. To describe incidents and potential dangers more thoroughly, further studies are needed. Furthermore, day-to-day vegetable intake, eating patterns, general status and the overall body weight of a person should be taken into account. Cadmium (Cd) is a toxicity ia result of long term exposure and “*itai-itai*” infection in Japan during 1950’s is an eye opening instance. Arrangement of rules and rules has been created in numerous nations and worldwide associations to manage the examination on wellbeing impact of Cd contamination [111].

7. Bioremediation of cadmium

According to EPA, bioremediation can be defined as “technique which uses naturally occurring microorganisms to break down hazardous substances into less toxic or non-toxic substances [111].”

7.1 Techniques of bioremediation

a. In-situ Bioremediation: This technique follows on-site remediation of polluted soil using sustainable technologies [112, 113].

b. Ex-situ Bioremediation: This method based on cleaning contaminated site elsewhere i.e. not in the site of pollution.

7.2 Types

a. Phytoremediation: Phytoremediation is an eco-friendly option for rejuvenating contaminated site using plants and microbes. Plants suitable for

phytoremediation techniques must have important characters like high above ground biomass with vigorous growth, proliferated root system and metal accumulating characters [114].

b. Phytoextraction: Phytoextraction can be described as a metal extracting character by plant roots and subsequently plants are subjected to burial in some other place or incineration. Taxonomically plants species which are excellent metal extractor's belongs to families like *Scrophulariaceae*, *Lamiaceae*, *Asteraceae*, *Euphorbiaceae*, and *Brassicaceae*. However, plant species like *Celosia argentea* L. [115], *Salix mucronata* L. [61], *Cassia alata* L. [116], *Solanum melonae* L., *Momordica charantia* L. [117], *Kummerowia striata* L. [118], and *Swietenia macrophylla* L. [65], may be used as potential plant choices to increase the process of Cd phytoextraction. Moreover, a sub-division of phytoextraction, known as chelate-assisted phytoextraction, is also used as a possible solution for metals that have no hyperaccumulator species using EDTA or citric acid [66, 119].

7.3 Microorganisms for bioremediation

Microbe's works in both active and passive mode and microbial species like bacteria, fungi and algae can be used as a potential option for eco-friendly remediation techniques [93]. Bacteria's are very effective for cleaning contaminated site due to its unique metabolic characters and tolerance to harsh conditions [120]. Several heavy metals have been tested using bacteria species like *Flavobacterium*, *Pseudomonas*, *Enterobacter*, *Bacillus*, and *Micrococcus* sp. Their great bio-sorption ability is due to high surface-to-volume ratios and the potential active chemosorption sites (teichoic acid) on the cell wall [121]. Abioye and his coworkers [122] reported successful use of bacterial species like *Bacillus subtilis* L., *B. megaterium* L., *Aspergillus niger* L., and *Penicillium* sp. for revive soils contaminated with lead (Pb) and cadmium (Cd). Fungal species like *Coprinopsis atramentaria* L. can bioaccumulate more than 75% of Cd of the contaminated site by 1 mg L^{-1} [123]. Goher and his co-authors [68] reported cleaning of Cd- contaminated site using dead algal cells of *Chlorella vulgaris* L.

8. Conclusions

This present chapter summarizes the various sources of Cd in environment and its toxic effects on plant and human being as well as suggested some approaches of bioremediation to mitigate the Cd pollution from environment. Anthropogenic activities are the key pathway to contaminate the environment with Cd which ultimately accumulated in various leafy vegetables and food grains. Consumption of this high Cd containing food causes several toxic symptoms in human being and leads to malfunctioning of multiple human organs. To reduce the Cd accumulation in food grain various amelioration strategies has been adopted among them use of microbes to decrease Cd uptake by plants seems to have great prospective. Moreover, some microbes may increase amounts of Cd due to their biochemical processes, and their implementation may also worsen problems with soil pollution. Use It is also suggested to characterize the microbes and tested them in laboratory and field condition prior to their use in agricultural soils, thus maintaining soil quality and food safety.

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